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INVESTIGATIONS AND TESTS IN THE TOWING BASIN AT GUIDONIA

By C. Cremona

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I. INTRODUCTION

The Hydrodynamic Section forms part of the research equipment directly concerned with the development of Italian military aeronautics the laboratories of which are situated in a locality near Rome, bearing the name Guidonia.

The principal object of the Hydrodynamic Section is the investigation of the forms and the study of the behavior of the hulls and floats of seaplanes.

Naturally, side by side with this experimental work, corresponding theoretical investigations are conducted for clarifying and defining the still somewhat vague concepts of hydrodynamics, which even today must be considered as the branch of fluid dynamics in which the most uncertainties and unknowns are to be found, and that still is the most difficult to express by precise laws and simple formulas.

The experimental activity of the section has been oriented so as to obtain results most nearly approaching actual conditions and most adapted to the special technical requirements of the seaplane designer. In particular, as regards tests on the hulls and floats of seaplanes, for example, the system of testing models at specific scales has been discontinued because it could offer only the alternatives of acceptance or rejection, acceptance being subject to the particularly determined and restricted conditions of the designer. It is impossible to predict the behavior of a hull even if only slight changes are obtained in load and trim, however great the competence and "artistic intuition" of the designer. In conformity with other hydrodynamic testing laboratories, nondimensional coefficients have been adopted, defined as follows:

*"Le Ricerche e le Esperienze Presso la Vasca Idrodinamica di Guidonia." Reprint of paper presented at meeting of Lilienthal-Gesellschaft für Luftfahrtforschung, October 12-15, 1938, Berlin.

Load coefficient $C_Q = Q/\rho\ b^3$

Resistance coefficient $C_R = R/\rho\ b^3$

Speed coefficient $C_V = V/\sqrt{g\ b}$

Moment coefficient $C_M = M/\rho\ b^4$

where ρ is the specific weight of the water and b a reference length of the hull (beam at step).

A model hull is tested at a series of loads, Q, and at various fixed trims, ϑ, and at speeds, V, and the resistance and moments are obtained. A series of tests of this kind requires about 200 runs of the towing carriage.

When, as a result of the designer's study of the nondimensional hydrodynamic curves, the hull assumes a final dimensioned form a dynamic model is constructed at suitable scale. The purpose of this model is to overcome the uncertainties that result from the combination of the hydrodynamic forces on the hull, the aerodynamic forces on the wings, the interference effects and the inertia effects from accelerated motion. This model is constructed with corresponding weight and distribution of mass, with movable surfaces (flaps) and in some cases with movable control surfaces (elevators) (fig. 1).

By towing the model at variable speed from zero up to the theoretical take-off the reliability of the assumptions made and the degree of approximation of the calculations may be checked. It is furthermore possible to determine unsuitable constructions in the general structure of the seaplane (attachment of the wing struts to the hull, position of the horizontal tail plane, position of the propellers, etc., in relation to the size of the wave formation).

II. EXPERIMENTAL METHODS

The towing tank at Guidonia was designed on the basis of the above considerations. It possesses two towing carriages, each of different characteristics and designed for different purposes, running over a tank 460 meters (1,518 ft.) long, 6 meters (19.8 ft.) wide, and 3.50 meters (11.55 ft.) deep.

A) The Bridge Towing Carriage

The first of these, of bridge-type construction (reference 1) has been designed and built so that in addition to tests on seaplane hulls it can also be used for tests on models of ship hulls partly or fully submerged (fig. 2).

The metal structure is of electrically welded steel tubing (airplane tubes) the tubes being covered with a fairing to reduce the resistance to motion and the aerodynamic disturbances produced by the structure on the model. The carriage rests on four wheels fitted with pneumatic tires to give the necessary adhesion in starting so as to attain high speeds in the shortest possible distance. Each of the four wheels is separately driven by a direct current electric motor. The measuring apparatus is located at the center of the carriage.

The total weight of the carriage ready for testing and complete with crew (six persons) is 6,000 kilograms. With a power of 100 horsepower, the carriage can attain a maximum speed of 20 meters per second and has a minimum speed of 5 centimeters per second. The intermediate speeds can be varied in small steps.

B) The Side Towing Carriage.

The second carriage, of a new and original design, is entirely enclosed in a fairing and runs along the side of the tank. It has one or two parallel cantilever arms which extend to the center line of the tank and at the end of which is suspended the recording apparatus (reference 2).

The carriage is constructed of a large steel tube to which are electrically welded other pieces of tube for the support of the cantilever arms and the flange on which is mounted the single direct current motor which is coupled to the drive wheel. To attain the necessary adhesion, this carriage also runs on pneumatic tires (three wheels). With a 100-horsepower motor it can reach a speed of 40 meters per second within a minimum interval of 10 seconds, intermediate speeds being obtained by fine regulation (fig. 3). The weight of the carriage when fully equipped (2 persons) is 2,000 kilograms.

C) The Catapult Installation

For special experimental requirements, when it is desired to attain very high speeds in the shortest possible time, the Section can avail itself of a compressed-air catapult. With a maximum pressure of 50 atmospheres, a speed of 100 meters per second may be attained.

D) The Auxiliary Laboratories

The equipment is completed by machine rooms for the conversion of electric energy, research laboratories, offices, storage rooms, machine shop, records, etc.

III. THE DYNAMOMETER

Particular care and special attention have been given to the solution of the problem of the dynamometer. Because appreciable progress has been made in this field, I believe it of interest to call attention to the development in Italy and I hope to be able soon to present the results of our studies.

As has been said above, in order to present the results obtained on the hulls in nondimensional form, it is necessary to make the tests at fixed trims. Under these conditions the measuring of the moments is very difficult (and hence only approximate) because it is practically impossible to bring the scale back to the zero position during the test. It is necessary to utilize the deformation of an elastic material in order to determine the value of the moment. The deformation although reduced by suitable means is nevertheless large enough to bring about a change in the trim ϑ so that a careful measurement of this angle is necessary.

It is known that hydrodynamic tests do not have a continuous and stable character and hence in order to measure the angle ϑ, it is necessary to record it. All this appreciably complicates the construction of the dynamometer, the plotting of the curves, and the computation, and makes the results very largely approximate. It was therefore necessary to find an elastic material that could indicate the forces to be measured over a sufficiently large range (from 0 to 100 kg) with sufficient sensitivity and without appreciable deformation. Investigations were therefore conducted by Prof. L. Crocco any myself on the methods available for this purpose but all had to be rejected either because of the poor sensitivity to small loads, because of the difficulty in calibration, or because of the delicacy of the measurements which took on the character of laboratory operations (reference 3) poorly adapted to the use of the not entirely technical personnel available at Guidonia.

The choice fell upon a new technical method that first appeared in Germany and is known today all over the world and is used to a large extent also in Italy, namely, 'bellows-type springs. When the latter are filled with liquid they assume an extreme rigidity and when connected to a manometer tube suitably proportioned possess a truly exceptional sensitivity capable of indicating a change of only one gram when loaded to several hundred kilograms although the load may be rapidly varied (fig. 4). At maximum load the deformation can be reduced to a few hundredths of a millimeter if the dimensions of the spring body remain within fixed limits. When the load is removed there is an accurate return to the zero position (reference 4).

This device offers not only the advantage of permitting the reading or recording of the forces or of their variation at considerable distances from their point of application but also eliminates the mechanical complication of the transmission members (parallelograms, etc.) of the normal balances, with the unavoidable difficulties arising from the friction and inertia of the oscillating masses.

The method of operation of the mechanism is based on the well-known principle of converting the force to be measured into hydraulic pressure. The spring body replaces the cylinder-piston system and eliminates the difficulties due to friction and leakage.

Figure 5 shows a schematic diagram of the mechanism. The force to be measured, F, acts on one of the covers of the spring (in the sketch the force and spring are vertical although the direction may be arbitrary). The spring is filled with a fluid which by means of tube T communicates the manometer M. The same liquid that fills the spring may be used as the liquid in the manometer but it is convenient to adopt a liquid of greater density in order that a change in the height of the manometer tube may correspond to a greater increase in pressure and thus the advantage gained of a decrease in the variation of the volume of the body C and hence of the displacement of the force F. The liquid used to fill C and that of the manometer M come in contact in the vessel V whose cross section is regulated so as to reduce the oscillations of the level of the contact surface of the liquids.

Under the action of the force F, there is set up on the fluid in C a pressure p, which is propagated over the tube T and the vessel V and raises the height H of the liquid in M. The point of application of the force F is displaced by an amount h, which is inversely proportional to the ratio of the cross sections of C and of the tube M. With suitable dimensioning of these cross sections and corresponding choice in the manometer liquid, the displacement h can be maintained at a negligible value. There is thus eliminated also the effect of the mechanical rigidity of the spring.

Since we are dealing with the case of a liquid enclosed in pipes, it is convenient to keep the unavoidable oscillations down to a small value by the aid of suitable throttle valves.

In this connection a description will be given of the arrangement of the one-, two-, and three-component dynamometer for the towing carriage. The other apparatus of three or six components is based on the same principle. The three-component balance (reference 5) is schematically composed of:

a) A mechanical system consisting of a vertically movable rod A to which the model is attached. The rod is counterbalanced by weights and flexible bands, which pass over pulleys B. Dashpots C damp any pendulum oscillations of the rod. To this rod are attached two ground steel bars, which support guide rollers carried on the horizontal members of two linkage parallelograms D, which resolve the hydrodynamic forces and transmit them to the indicating apparatus E (fig. 6).

The possibility of changing the two linkages so as to make possible the measurement of components oblique or normal to the model has been foreseen. The two linkages are mounted on a support of cast light metal. The support rests on a large base plate that can rotate about the axis of the movable attachment rod so that the system may be revolved with respect to the direction of motion (drift). This angle, as well as the setting of the guide system, are read off on graduated circles provided with vernier and magnifying glass. The base plate is capable of vertical displacements by means of the simultaneous rotation of four threaded spindles attached to the corners of the plate for attachment to the towing carriage. The corresponding four steel precision nuts rest on the base plate.

b) A recording apparatus. The forces to be determined act upon the fluid-filled spring that in turn communicates by means of fluid-tight metal tubes with pressure measuring mercury columns, the height of which gives directly the value of the hydrodynamic forces (fig. 7).

The measurement takes place without appreciable displacement of the point of application (a few tenths of a millimeter for forces up to several hundred kilograms). With the aid of the adjustable throttle valves, any desired damping of the oscillations of the manometer columns may be obtained. Of the three pressure measuring elements two are connected to the linkage parallelograms and serve to measure the horizontal components of the force and of the moment while the third is connected at the upper end of the movable rod and is used for measuring the vertical component. There is provided the possibility of disconnecting the latter pressure element so as to leave the rod freely movable for measuring only two components. It is also possible to remove the upper parallelogram, and the rod with the corresponding guide of the lower parallelogram can be substituted for measuring a single component.

c) An electric recording arrangement of the "Usigli" type construction (reference 6) that can be mounted in any position on the carriage and whose readings are independent of the variations in voltage of the feed lines of the direct current system. The system consists of three transmitting elements and three recording devices, which are electrically connected with each other across a differential galvanometer (fig. 7). The transmitting elements are each of a calibrated chromium nickel wire, which is stretched inside the manometer tube. The electrical resistance of the free end of this wire varies linearly with the height of the manometer column and hence with the forces to be measured.

The differential galvanometers are perfectly balanced and provided with damping and are inclosed in suitable casings that are mounted on vibration proof supports, so that the vibrations of the carriage can have no effect. The recording devices themselves possess servo motors that are controlled by contacts which, in turn, are actuated by the corresponding differential galvanometer. The servo motor not only moves the recording stylus but also regulates a resistance equal to the transmitting resistance so that the differential galvanometer returns to the equilibrium position after each change in the pressure head.

The servo motors permit a high speed of the stylus and, in order to avoid overregulation and impacts, are provided with electromagnetic brakes.

Three recording devices are provided; one for each component. If only one or two components are to be measured the free apparatus may be used for recording other quantities of interest to the test being conducted. With the aid of an arrangement of photocells and electrical time-measuring apparatus there are also recorded the paths and times for the determination of the speeds.

IV. TESTS AND INVESTIGATIONS

In this first period of its activity, the Hydrodynamic Section has, in addition to work for the ministry, carried out systematic tests of a general nature with regard to problems of general interest. The work of collecting, arranging, and publishing the results is largely in progress.

The installing and improving of the equipment made it appear advisable to postpone the publication of test results, although they will appear shortly in the "Atti di Guidonia."

A. Tests

a) Tests of hulls and floats.- Among the most important test results are those obtained from the systematic series of tests on the twin floats of the seaplane Cant Z 505, which in its various editions has achieved 16 world records (reference 7). The tests were carried out on a pair of similar floats. The dimensions in terms of the beam at the step, taken as the unit and set equal to 100, are given in figure 8.

The model was tested at five different distances d from the center line of the floats, multiples of the beam b at the step; namely, 3, 4, 5, 6, and 7 times b and infinity (single hull). For each of these conditions, the load Q and the trim ϑ were varied and the resistance R was obtained as a function of the forward velocity V. About 1,000 runs were made with the towing carriage for which, thanks to the particular equipment available, about 15 working days were consumed (reference 8).

An innovation was introduced in that in defining the quantity b, which appears in the denominator of equation (1), this quantity does not represent the sum of the widths of both steps of the pair of floats but a mean hydrodynamic step which makes possible a logical comparison of the characteristics of a pair of floats (for equal displacement, for instance) with the characteristics of a geometrically similar single float. Useful comparative values are obtained and also an extension in the choice possibilities for the designer.

Let A and B be two geometrically similar bodies resting in similar attitudes on a plane a (fig. 9). Let x be a system of abscissas perpendicular to a and with the origin on the latter. If for the body A there holds the relation

$$S_x = f(x)$$

where S_x is the section of the solid cut off by a plane parallel to a and at distance x from it, then for the second solid B, there will hold the expression

$$s_{\frac{x}{K}} = \frac{1}{K^2} S_x = \frac{1}{K^2} f(x)$$

where K is the linear ratio of similitude.

Also, if for solid A, the volume is

$$V_x = \int_0^x f(x)\, d\, x$$

then for solid B the corresponding volume will be given by

$$v_{\frac{x}{K}} = \frac{1}{K^3} V_x = \frac{1}{K^3} \int_0^x f(x)\, d\, x$$

Denoting by n the ratio between the weights, the solids being assumed homogeneous and of the same density δ, we may write

$$\frac{\delta V_x}{\delta v_{\frac{x}{K}}} = n = K^3$$

i.e.,

$$K = \sqrt[3]{n}$$

Thus, body A is equivalent to n bodies B if the linear ratio of similitude K is equal to the cube root of n. In particular, in order that a body be equivalent to two equal bodies similar to it and of the same density, it is necessary that the ratio of geometrical similitude be

$$K = \sqrt[3]{2} = 1.2599$$

In equation (1) the value of b has been assumed as 1.26 times the beam b, of one of the steps of the floats.

The results obtained may thus be applied to a single as well as to twin floats if in the relations

$$R = C_R \rho b^3$$

$$Q = C_Q \rho b^3$$

$$V = C_V g^{\frac{1}{2}} b^{\frac{1}{2}}$$

the above equivalence is taken into account and if as a first approximation, there is neglected the hydrodynamic interference (reference 9) of the two floats or the required corrections are made.

The first set of results that are presented in tables I to V gives for $d = 3$ b the variation in C_R as a function of V for $\vartheta = 0^\circ, 2^\circ, 4^\circ, 6^\circ, 8^\circ$, and C_Q = 1.575; 1.260; 0.945; 0.630; 0.315. The other sets refer to $d = 4$ b, 5 b, 6 b, 7 b, and ∞ b, applicable to the same conditions and are given in table VI to XXX.

An examination of these results is very interesting, particularly if in order to facilitate comparison of the variables under consideration, there are observed the various combinations of these (figs. 10, 11, 12, 13, and 14).

With the aid of these data the designer, if, for example, he is restricted in his choice of the characteristics of the power plant (reference 10) and the aerodynamic characteristics, is in a position to fix the maximum value of the hydrodynamic resistance that he desires to attain in getaway, as a function, for example, of the getaway time and from this derive the most favorable distance between the two floats as well as the most favorable arrangement of the wings (reference 11), so that the aerodynamic lift of the airfoils (for the most favorable speed $C_V(C_R \longrightarrow \text{min.})$ and hence of trim ϑ given by the experimental curves) corresponds to the value of C_Q, which gives the least C_R. There are thus fixed the structural dimensions of the hull and the floats in relation to the design data.

With the assignment of dimensions, the model assumes the character of a definite seaplane (fig. 15). The model is then attached to the side towing carriage and is subjected to a series of test runs in relation to wave formation, etc. With the aid of a family of curves, it is possible to calculate, for example:

a) The get-away characteristics for various useful loads.

b) The maximum admissible useful load for definite get-away characteristics.

In these cases the computed results can be checked by means of the side towing carriage.

The large number of best loads for the seaplane "Cant Z 505" clearly shows the technical usefulness of this procedure.

A further group of systematic tests was conducted for the Caproni Firm on the model of an amphibian hull with retractable landing gear. The results of these interesting investigations are being assembled and will be published as soon as possible.

<u>b) Tests on motor boats</u>.- The Section was also entrusted with the task of investigating several types of motor-boat hulls for the group of personnel of the M.V.S.N. taking part in the Gold Cup races in Detroit and the President's Cup races on the Potomac (U.S.A.).

The tests already conducted made it possible to obtain very appreciable advantages in regard to the resistance and the stability; and the boat selected, bearing the name of "Alagi," has obtained the world's best performance in the 12-liter class of boats and took second place in both races because of interruptions in the fuel supply to the engine - although it made the fastest round in both races.

The Hydrodynamic Section has also studied a type of planing boat that in the previous year won the classic race on the Danube and this year won the Pavia - Venice race, making the distance in half the time employed by the others.

These tests on motor boats were extended to very high speeds, making use also of the side towing carriage and very interesting findings were made in relation to the studies and other tests of Sottorf, Perring and Johnston, and Sokalov, etc., and I have undertaken to publish these data at the first opportunity as soon as I have made some check tests.

c) Tests on torpedo-shaped bodies.- In connection with the tests on immersed floats, the Hydrodynamic Section, in cooperation with the Minister of the Navy was much occupied with the problem of the motion of spindle-shaped bodies with insufficient control surfaces (torpedoes), carrying out several series of systematic tests with the object of improving the behavior of these bodies particularly with regard to their stability (reference 12).

I believe that the method adopted for the determination of the resistance is of interest. The determination is always rendered somewhat uncertain by the difficulty of estimating the interferences of the suspension rod whose dimensions and strength make it necessary to limit the speeds to very low values far removed from the velocities corresponding to desirable Reynolds Numbers.

Torpedoes generally have insufficient control surface or none at all. Their stability in trim depends on the setting of the depth rudders. The determination of the trim is relatively simple and reliable. During the motion with a given angular setting in the instantaneous direction of the speed V, there is set up a lift which must balance the centrifugal force. If m denotes the mass of the body, l one of its linear dimensions, ρ the density of the medium, R the instantaneous radius of curvature, and k a coefficient of proportionality as a function of the trim

$$\frac{m\ V^2}{R} = k\ \rho\ l^2\ V^2$$

from which is obtained

$$R = \frac{m}{k\ \rho\ l^2}$$

which shows that the trajectory is circular and independent of the speed. If this body is projected into the water along a known direction and with a known velocity and there is measured the time required until it comes up again, it is possible to measure the uniformly retarded motion and then to determine the resistance. For this purpose, there is employed the catapult apparatus which permits the variation of V and the angle of entry into the water. These tests are now in progress.

B. Theoretical Investigations

a) Pressure distribution on geometrically simple bodies.- In the field of theoretical investigation, the Hydrodynamic Section is conducting pressure-distribution tests along the surface of a sphere at various velocities. These tests, of great theoretical interest and quite common in the field of aerodynamics, are far rarer in number in the field of hydrodynamics. It was found necessary to develop a special differential manometer for these fine measurements. These tests are in progress at the present time.

b) Propagation of small wave motions.- Also in the theoretical field, tests are being conducted to determine the law of propagation of small waves that are produced by a perfectly geometric body (sphere) dropped into the water from various heights. The method is based on the change in resistance of two plates of suitable cross section immersed in water, the change in resistance being indicated by the change in light intensity of a cathode ray oscillograph.

c) Planing and submerged surfaces.- Finally, with the cooperation of Crescentini, a collaborator of Professor Forlanini, tests are being conducted on lifting surfaces moving below or on the surface of the water. The possibility of obtaining greater experimental speeds will provide important means of study.

V. CONCLUSION

I regret that I was unable to present at this meeting all the results of the work conducted but I hope to be able to make them public as soon as possible and I wish to express the desire for a closer cooperation among the four hydrodynamic testing institutes that particularly occupy themselves with aeronautical investigation, in Germany, The United States, England, and Italy. There will thus result a greater and more rapid development of this branch of aeronautics for which, with the ever-increasing weights and dimensions of seaplanes, a brilliant future may be expected.

Translation by S. Reiss,
National Advisory Committee
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$d = 3b$ **Tabella I** $\vartheta = 0°$

C_V	C_R: $Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.0158	0.0205	0.0255	0.0126	
1.654	0.0536	0.1000	0.1392	0.1575	
2.481	0.0710	0.1400	0.2140	0.2580	
3.308	0.0730	0.1510	0.2580	0.3210	
4.135	0.0882	0.1465	0.2300	0.3060	
4.962	0.1100	0.1560	0.2110	0.2870	
5.789	0.1230	0.1765	0.2140	0.2650	
6.616	0.1640	0.1960	0.2280	0.2680	
7.443	0.1825	0.2390	0.2650	0.3211	

$d = 3b$ **Tabella II** $\vartheta = 2°$

C_V	C_R: $Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.01575	0.02042	0.0246	0.0308	0.0390
1.654	0.05827	0.0914	0.1128	0.148	0.186
2.481	0.0687	0.1386	0.200	0.268	0.334
3.308	0.0677	0.1354	0.2046	0.303	0.413
4.135	0.0845	0.1197	0.1763	0.261	0.396
4.962	0.0945	0.1386	0.159	0.230	0.312
5.789	0.0976	0.1418	0.1637	0.228	0.308
6.616			0.189		

$d = 3b$ **Tabella III** $\vartheta = 4°$

C_V	C_R: $Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.0183	0.0126	0.0312	0.037	0.0472
1.654	0.0623	0.0945	0.1260	0.1605	0.2205
2.481	0.0740	0.1325	0.2030	0.2680	0.3370
3.308	0.0778	0.1230	0.1825	0.2710	0.3720
4.135	0.0976	0.1260	0.1670	0.2330	0.3020
4.962	0.1260	0.1392	0.1765	0.2280	0.2770
5.789		0.1765	0.2015	0.2580	0.2995
6.616				(0.268)	

$d = 3b$ **Tabella IV** $\vartheta = 6°$

C_V	C_R: $Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.0157	0.0192	0.0284	0.0410	0.0498
1.654	0.0598	0.1040	0.1385	0.1670	0.2205
2.481	0.0750	0.1390	0.2080	0.2930	0.356
3.308	0.0882	0.1420	0.1985	0.2770	0.362
4.135	(0.1135)	0.1575	0.1985	0.2600	0.337
4.962		0.1950	0.2175	0.2640	0.321

$d = 3b$ **Tabella V** $\vartheta = 8°$

C_V	C_R: $Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.0249	0.04095	0.0457	0.063	0.0693
1.654	0.0646	0.1130	0.1514	0.2017	0.246
2.481	0.0759	0.1390	0.2240	0.309	0.394
3.308	0.1090	0.1610	0.2350	0.309	0.381
4.135	0.1355	0.1830	0.2440	0.3057	0.372
4.962	0.1420	0.2180	0.2550	0.334	0.384
5.789	0.1355	0.255		0.356	
6.616	0.1450				
7.443	0.1609				

$d = 4b$ **Tabella VI** $\vartheta = 0°$

C_V	C_R: $Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.01575	0.02042	0.02205	0.0315	0.0362
1.654	0.05826	0.0914	0.1197	0.1542	0.1732
2.481	0.06615	0.1308	0.211	0.277	0.3275
3.308	0.0694	0.1322	0.2293	0.331	0.4035
4.135	0.0819	0.1339	0.1983	0.2925	0.3875
4.962	0.0976	0.1401	0.1952	0.258	0.331
5.789	0.0976	0.1574	0.2015	0.2504	0.3023
6.616	0.1386	0.1748	0.2141	0.252	0.3055
7.443	0.1701	0.2042	0.2457	0.2707	0.315

$d = 4b$ **Tabella VII** $\vartheta = 2°$

C_V	C_R: $Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.01574	0.02204	0.00945	0.00945	0.02993
1.654	0.0657	0.08975	0.0945	0.1322	0.156
2.481	0.0615	0.1308	0.1884	0.277	0.3685
3.308	0.0605	0.1102	0.242	0.2802	0.3764
4.135	0.0725	0.1165	0.1637	0.230	0.3102
4.962	0.063	0.118	0.170	0.2173	0.277
5.789	0.0693	0.1418	0.1638	0.2264	0.258
6.616	0.104	0.1432	0.189	0.2487	0.271
7.443	0.1291	0.170	0.2267	0.255	0.299

$d = 4b$ **Tabella VIII** $\vartheta = 4°$

C_V	C_R: $Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.0126	0.0252	0.02835	0.0362	0.063
1.654	0.0599	0.0945	0.126	0.1512	0.1763
2.481	0.0693	0.1276	0.195	0.28	0.362
3.308	0.0756	0.1243	0.192	0.268	0.3685
4.135	0.1009	0.1354	0.1794	0.233	0.324
4.962	0.104	0.176	0.192	0.225	0.2945
5.789			0.2237	0.2708	0.315
6.616			0.2347	0.274	0.310

$d = 4b$ **Tabella IX** $\vartheta = 6°$

C_V	C_R: $Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.0315	0.0378	0.05045	0.06145	0.0756
1.654	0.0693	0.1133	0.129	0.1575	0.372
2.481	0.0882	0.1465	0.2017	0.2895	0.3907
3.308	0.1023	0.1542	0.208	0.280	0.375
4.135	0.137	0.170	0.214	0.2645	0.346
4.962	0.167	0.1967	0.2265	0.274	0.337
5.789	0.2046	0.230	0.2423		0.337
6.616	0.2495				0.351

$d = 4b$ **Tabella X** $\vartheta = 8°$

C_V	C_R: $Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.2835	0.0441	0.063	0.0772	0.0976
1.654	0.0677	0.1165	0.1574	0.208	0.236
2.481	0.0882	0.1511	0.222	0.3055	0.3905
3.308	0.1133	0.167	0.233	0.312	0.394
4.135	0.1385	0.1965	0.236	0.3086	0.386
4.962	0.1385	0.2203	0.2645	0.318	0.3873
5.789	0.1322	0.252	0.3005	0.346	0.403
6.616	0.1511		0.3435		

$d = 5b$ **Tabella XI** $\vartheta = 0°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.022	0.028	0.035	0.047	0.053
1.654	0.044	0.104	0.088	0.140	0.147
2.481	0.065	0.140	0.208	0.268	0.330
3.308	0.071	0.139	0.236	0.339	0.630
4.135	0.085	0.138	0.205	0.295	0.397
4.962	0.101	0.148	0.205	0.266	0.353
5.789	0.096	0.157	0.224	0.263	0.334
6.616	0.142	0.192	0.236	0.268	0.350

$d = 5b$ **Tabella XII** $\vartheta = 2°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.022	0.028	0.036	0.036	0.044
1.654	0.058	0.088	0.112	0.135	0.148
2.481	0.063	0.132	0.208	0.290	0.397
3.308	0.069	0.117	0.198	0.286	0.404
4.135	0.076	0.117	0.175	0.243	0.340
4.962	0.069	0.129	0.170	0.222	0.293
5.789	0.073	0.137	0.186	0.240	0.268
6.616	0.088	0.161	0.198	0.236	0.289

$d = 5b$ **Tabella XIII** $\vartheta = 4°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.022	0.025	0.035	0.044	0.054
1.654	0.061	0.101	0.120	0.148	0.179
2.481	0.077	0.134	0.215	0.284	0.378
3.308	0.081	0.126	0.200	0.276	0.382
4.135	0.098	0.131	0.184	0.246	0.318
4.962	0.107	0.151	0.192	0.233	0.290
5.789	0.131	0.187	0.227	0.261	0.312
6.616			0.240	0.270	0.305

$d = 5b$ **Tabella XIV** $\vartheta = 6°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.022	0.029	0.039	0.054	0.061
1.654	0.063	0.117	0.145	0.170	0.205
2.481	0.079	0.140	0.206	0.228	0.369
3.308	0.095	0.151	0.205	0.284	0.379
4.135	0.128	0.165	0.203	0.277	0.350
4.962	0.140	0.188	0.225	0.274	0.334
5.789	0.180	0.205	0.261	0.312	0.359

$d = 5b$ **Tabella XV** $\vartheta = 8°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.030	0.041	0.050	0.060	0.069
1.654	0.069	0.120	0.158	0.202	0.233
2.481	0.088	0.154	0.227	0.315	0.395
3.308	0.123	0.164	0.236	0.318	0.397
4.135	0.142	0.192	0.249	0.323	0.389
4.962	0.135	0.208	0.280	0.340	0.394
5.789	0.139	0.214	0.291	0.372	0.428
6.616	0.157		0.350	0.407	0.460

$d = 6b$ **Tabella XVI** $\vartheta = 0°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.008	0.027	0.120	0.038	0.038
1.654	0.050	0.091	0.479	0.151	0.189
2.481	0.063	0.129	0.700	0.221	0.328
3.308	0.075	0.132	0.080	0.340	0.385
4.135	0.088	0.139	0.920	0.290	0.385
4.962	0.107	0.151	0.840	0.265	0.343
5.789	0.101	0.158	0.845	0.266	0.318
6.616	0.155	0.164	(0.970)	0.309	0.309

$d = 6b$ **Tabella XVII** $\vartheta = 2°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.025	0.032	0.050	0.063	0.082
1.654	0.057	0.088	0.113	0.151	0.175
2.481	0.061	0.133	0.202	0.248	0.356
3.308	0.069	0.113	0.189	0.273	0.390
4.135	0.073	0.113	0.167	0.268	0.337
4.962	0.082	0.126	0.172	0.262	0.290
5.789	0.088	0.129	0.173	0.238	0.276
6.616			0.192	0.235	0.271

$d = 6b$ **Tabella XVIII** $\vartheta = 4°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.022	0.034	0.041	0.060	0.076
1.654	0.055	0.095	0.126	0.157	0.189
2.481	0.066	0.129	0.205	0.224	0.388
3.308	0.074	0.126	0.195	0.277	0.375
4.135	0.088	0.127	0.173	0.246	0.322
4.692	0.095	0.140	0.181	0.233	0.290
5.789	0.095	0.161	0.214	0.252	0.308
6.616				0.263	0.296

$d = 6b$ **Tabella XIX** $\vartheta = 6°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.022	0.038	0.041	0.054	0.072
1.654	0.071	0.113	0.140	0.180	0.205
2.481	0.082	0.133	0.205	0.227	0.372
3.308	0.095	0.142	0.214	0.286	0.379
4.135	0.123	0.162	0.214	0.271	0.347
4.962	0.142	0.183	0.230	0.271	0.329
5.789			0.265	0.315	0.365

$d = 6b$ **Tabella XX** $\vartheta = 8°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.024	0.041	0.044	0.063	0.063
1.654	0.063	0.112	0.132	0.183	0.186
2.481	0.076	0.139	0.207	0.232	0.378
3.308	0.098	0.142	0.207	0.283	0.369
4.135	0.126	0.162	0.211	0.269	0.344
4.962	0.142	0.183	0.226	0.275	0.330
5.789	0.120	0.164	0.265	0.325	0.356

$d = 7b$ **Tabella XXI** $\vartheta = 0°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.0204	0.0220	0.0252	0.0441	0.0472
1.654	0.0614	0.0724	0.1307	0.1481	0.1732
2.481	0.0646	0.1339	0.2111	0.2772	0.2378
3.308	0.0756	0.1370	0.2237	0.3591	0.523
4.135	0.0929	0.1386	0.2111	0.2868	0.378
4.962	0.1071	0.1512	0.2063	0.2647	0.3308
5.789	0.0819	0.167	0.2173	0.2678	0.3088

$d = 7b$ **Tabella XXII** $\vartheta = 2°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}360$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.0157	0.0252	0.0283	0.0362	0.0504
1.654	0.0583	0.0913	0.1197	0.1575	0.2237
2.481	0.0551	0.1323	0.208	0.2772	0.3433
3.308	0.0614	0.1172	0.1906	0.2803	0.3828
4.135	0.0709	0.1213	0.1686	0.2347	0.323
4.962	0.0819	0.1291	0.1701	0.2205	0.2772
5.789		0.1481	0.1827	0.2362	0.2857
6.616		0.1591	0.1985	0.252	0.2898

$d = 7b$ **Tabella XXIII** $\vartheta = 4°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.0220	0.0362	0.0409	0.0441	0.0536
1.654	0.0614	0.1071	0.1276	0.1575	0.1764
2.481	0.0709	0.1276	0.208	0.263	0.3622
3.308	0.0772	0.1244	0.189	0.274	0.3685
4.135	0.0945	0.1307	0.1764	0.2458	0.3056
4.962	0.1071	0.1606	0.1954	0.2331	0.2867
3.789		0.1417	0.2001	0.2647	0.334
6.616				0.2662	0.315

$d = 7b$ **Tabella XXIV** $\vartheta = 6°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.0283	0.0362	0.0362	0.0504	0.0567
1.654	0.0583	0.1008	0.1449	0.1733	0.2079
2.481	0.0740	0.1339	0.2079	0.2882	0.3718
3.308	0.0929	0.1402	0.2079	0.2788	0.3718
4.135	0.1197	0.1575	0.2032	0.2662	0.3308
4.962	0.1370	0.1827	0.2158	0.3023	0.3182
5.789	0.1465	0.1733	0.2615	0.3134	0.334
6.616		0.2269	0.2882	0.3182	0.356

$d = 7b$ **Tabella XXV** $\vartheta = 8°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.0236	0.0362	0.0472	0.0662	0.0787
1.654	0.0598	0.1071	0.1606	0.1922	0.2362
2.481	0.0819	0.1465	0.2173	0.2992	0.3908
3.308	0.1134	0.1591	0.320	0.3023	0.3908
4.135	0.1307	0.1874	0.2427	0.3009	0.378
4.962	0.1213	0.2205	0.2647	0.3308	0.3875
5.789	0.137	0.2252	0.2882	0.3355	0.4095
6.616	0.1402	0.2961	0.3433	0.3843	0.441

$d = \infty$ **Tabella XXVI** $\vartheta = 0°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.018	0.024	0.024	0.024	
1.654	0.041	0.091	0.117	0.148	
2.481	0.047	0.123	0.195	0.268	
3.308	0.050	0.123	0.213	0.330	
4.135	0.055	0.120	0.189	0.274	
4.962	0.065	0.120	0.173	0.240	
5.789		0.117	0.173	0.225	
6.616		0.132	0.181	0.224	

$d = \infty$ **Tabella XXVII** $\vartheta = 2°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.0095	0.021	0.032	0.041	0.052
1.654	0.044	0.068	0.107	0.135	0.167
2.481	0.047	0.117	0.189	0.259	0.343
3.308	0.046	0.105	0.181	0.262	0.370
4.135	0.053	0.096	0.151	0.215	0.312
4.962	0.052	0.095	0.134	0.195	0.257
5.789	0.044	0.087	0.129	0.170	0.228
6.616	0.044	0.088	0.132	0.170	0.220

$d = \infty$ **Tabella XXVIII** $\vartheta = 4°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.019	0.030	0.038	0.029	0.044
1.654	0.049	0.091	0.118	0.142	0.170
2.481	0.057	0.117	0.180	0.271	0.365
3.308	0.054	0.107	0.176	0.250	0.353
4.135	0.065	0.096	0.142	0.211	0.290
4.962	0.057	0.106	0.142	0.187	0.204
5.789		0.113	0.169	0.199	0.204
6.616				0.202	0.247

$d = \infty$ **Tabella XXIX** $\vartheta = 6°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.022	0.033	0.038	0.044	0.049
1.654	0.057	0.101	0.142	0.170	0.211
2.481	0.063	0.129	0.199	0.277	0.375
3.308	0.073	0.128	0.191	0.269	0.356
4.135	0.097	0.134	0.188	0.249	0.318
4.962	0.088	0.145	0.186	0.241	0.296
5.789				0.265	0.312
6.616				0.290	

$d = \infty$ **Tabella XXX** $\vartheta = 8°$

C_V	C_R				
	$Cq = 0{,}315$	$Cq = 0{,}630$	$Cq = 0{,}945$	$Cq = 1{,}260$	$Cq = 1{,}575$
0.827	0.025	0.041	0.047	0.057	0.079
1.654	0.057	0.117	0.164	0.211	0.246
2.481	0.082	0.145	0.219	0.233	0.388
3.308	0.094	0.145	0.209	0.225	0.372
4.135	0.091	0.172	0.218	0.222	0.357
4.962	0.076	0.189	0.240	0.230	0.357
5.789	0.082	0.185	0.224	0.246	0.372
6.616	0.069	0.161	0.246	0.335	0.397

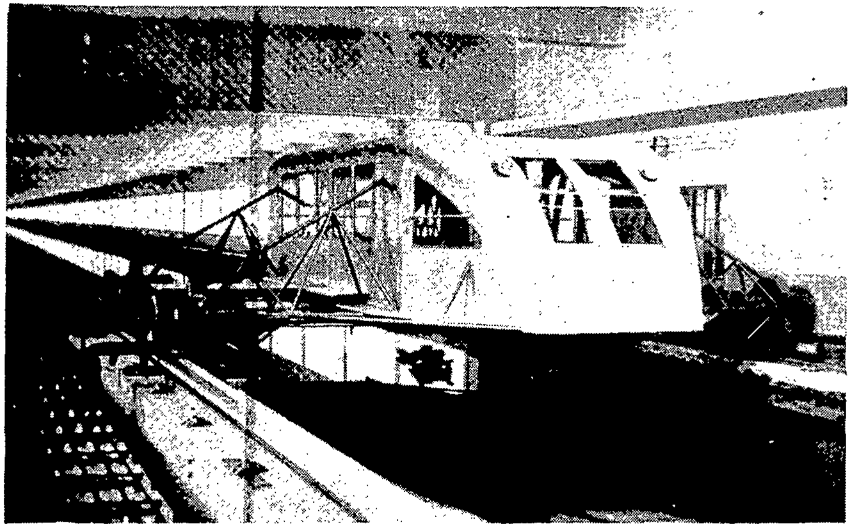

Figure 2

Figure 3

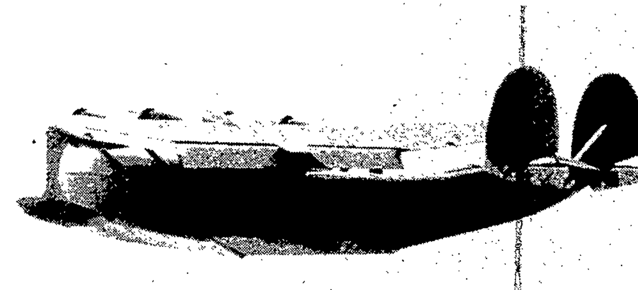

Figure 1

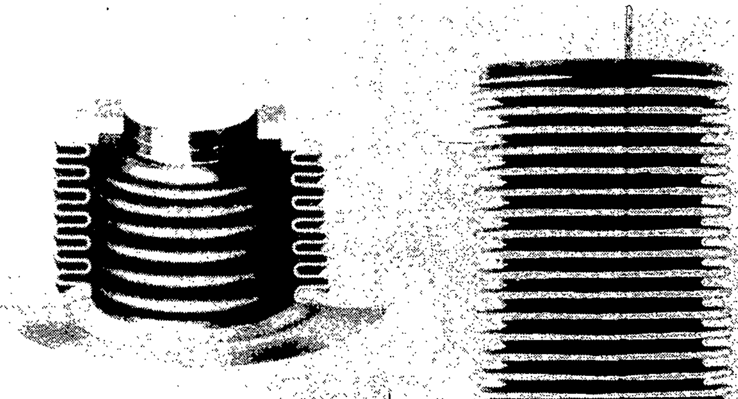

Figure 4

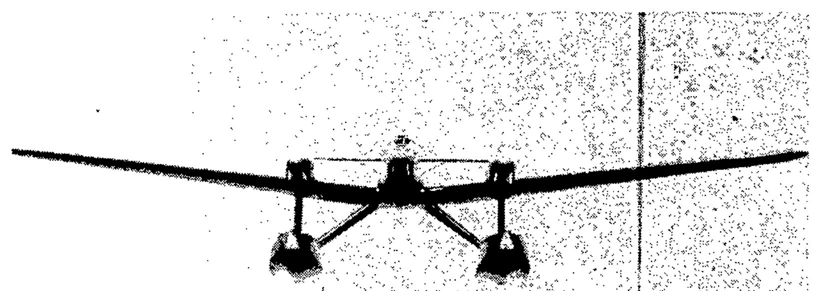

Figure 15

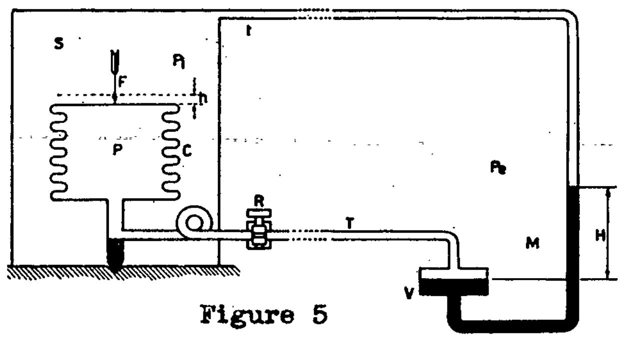

Figure 5

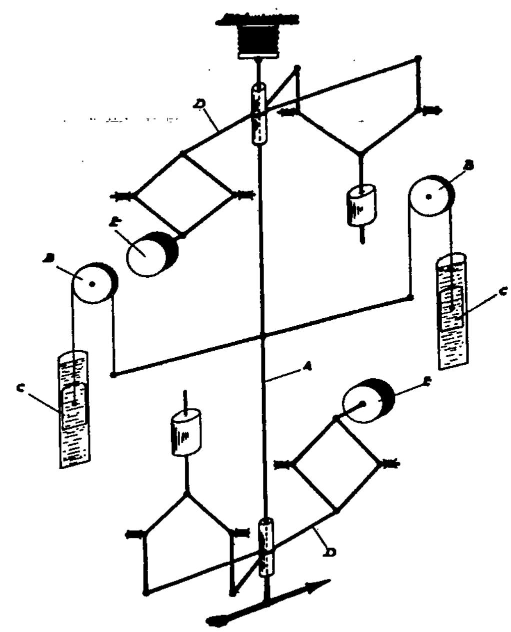

Figure 6

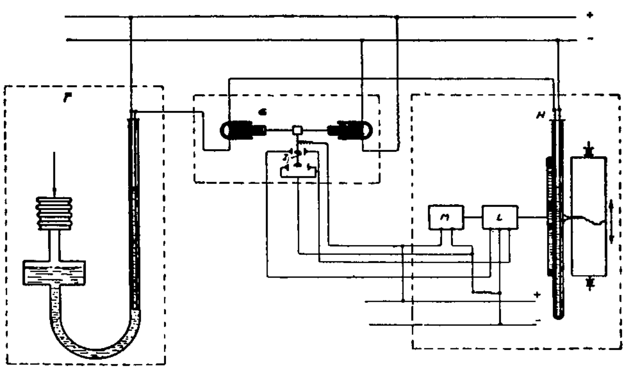

Figure 7

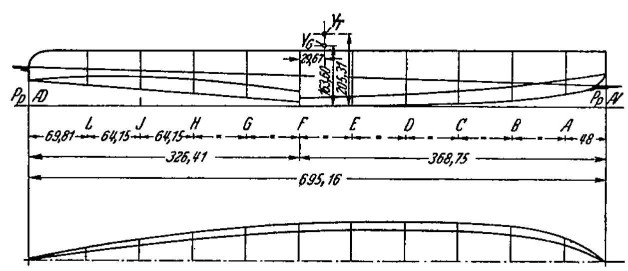

Figure 8

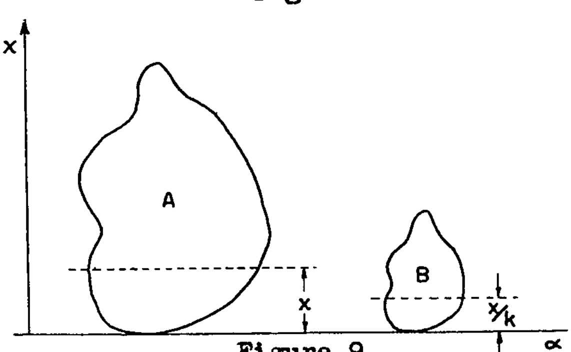

Figure 9

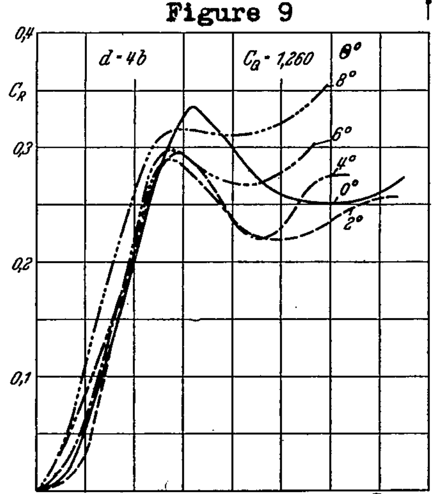

Figure 10

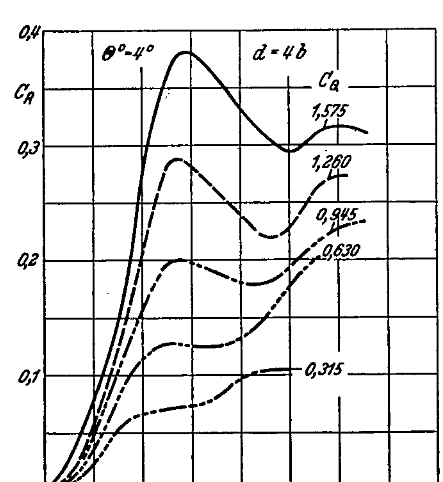

Fig. 11

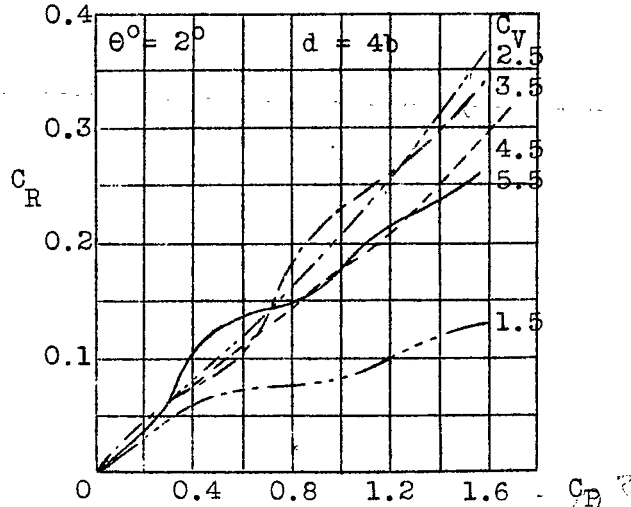

Figure 12

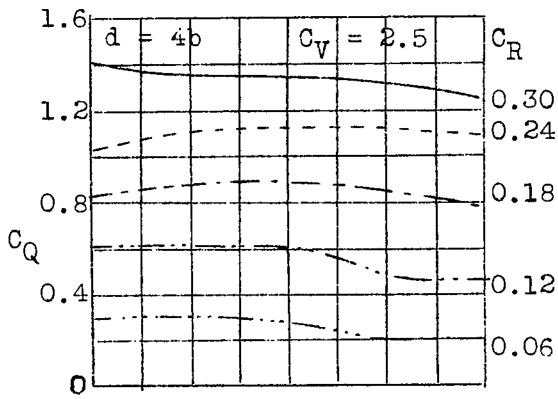

Figure 13

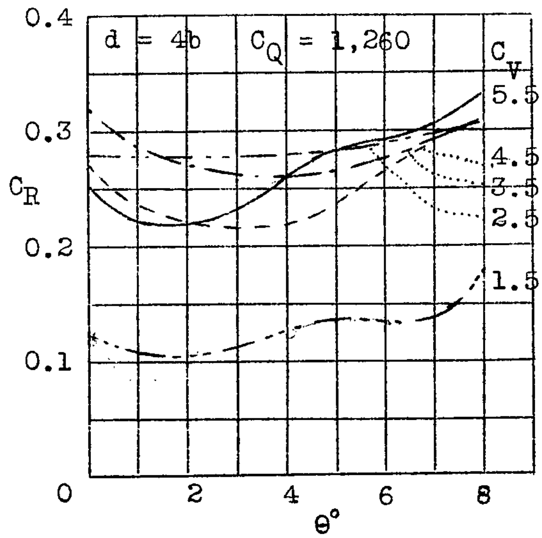

Figure 14